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INTRODUCTION

This report describes research performed during FY'87 at the Jet Propulsion Laboratory on the Modeling of Drop Containing Turbulent Eddies.

According to the Task Plan, the activities during FY'87 were devoted to the basic model formulation for evaporation of a cluster of drops which is embedded into a vortex.

RESEARCH PROGRESS

The point of departure for this analysis was our existing model of droplet evaporation in a cluster exposed to a convective flow⁽¹⁾. Some of the assumptions embedded in this model are:

- constant cluster volume (transient gas pressure)
- constant number of drops
- uniform gas density
- laminar gas flow
- adiabatically insulated cluster volume

To describe the behavior of drop-containing turbulent eddies some of these assumptions had to be relaxed so as to include the following effects:

- cluster volume change (constant gas pressure)
- non-uniform gas density
- turbulent gas flow
- mass and heat exchanges across the surface of the cluster.

The analysis was divided into 3 distinct problems which will have to be ultimately combined to yield the final model. These problems are in increasing levels of complexity:

- (1) dispersion of evaporating particles in a cluster,
- (2) mass and heat transfer across the surface of the cluster in situation (1), and
- (3) turbulent eddy behavior coupled to (2)

The model available at the end of FY'87 describes the evaporation of clusters of drops embedded in a surrounding hot gas and the exchange processes in terms of heat, mass, species and momentum transfer between the cluster and its surroundings. The gas pressure inside the cluster remains constant during evaporation whereas the volume of the cluster varies.

The results obtained with this model⁽²⁾ show in particular that: (1) for dense clusters there is substantial mass loss from the cluster during evaporation, most of it occurring during the initial stage and (2) if the cluster is dense, it collapses initially due to substantial internal cooling of gases (heat is transferred to the drops) after which the size of the cluster starts increasing again if turbulence is strong. For dilute clusters all these effects occur as well, although to a lesser extent.

One of the very important conclusions of the above work is that for dense cluster turbulence exchange processes are crucial in determining the lifetime of the drops in the cluster, as well as the behavior of the entire cluster. For dilute clusters the turbulence exchange processes are unimportant in determining the evaporation time. This is because the entire evaporation process is controlled by droplet heating and resulting gas phase cooling inside the cluster. For a denser cluster the gas phase will cool more and thus turbulence is crucial in bringing additional hot gas from the surroundings to maintain and/or promote evaporation. When the cluster is dilute, cooling is not important and consequently turbulence is not important either.

Another important conclusion of the above work⁽²⁾ is that turbulence helps evaporate larger clusters of drops faster when the cluster is dense. When the initial drop number density is fixed, a larger cluster of drops has more drops in it. Thus, at same initial ambient gas and drop temperature the cooling off effect of the gas phase will be larger and thus turbulence plays a larger role. Moreover, since the initial relative velocity between drops and gases is the same, a larger cluster is less penetrated by the outer convective flow and thus evaporates rather in a diffusive mode when compared to a smaller cluster which evaporates in a convective mode. In a diffusive mode evaporation is slower and thus turbulence has again an important role to play.

For dilute clusters there is very little sensitivity to turbulence as the size of the cluster is varied and the reasons are again those described above.

The practical implications of these results are that turbulence is important in sprays in two respects. First it breaks up the spray into small clusters that evaporate faster than the larger clusters and second, it transports hot gases from the surroundings of the cluster into the cluster thus promoting evaporation.

FUTURE WORK

This picture of droplet evaporation in clusters as described above is different from our initial expectations before the work was started. It had not been foreseen that cooling of the gases would be so strong as to induce an initial collapse of the cluster. Instead, it was thought that the evaporated mass would remain inside the cluster, the cluster would expand trapping all new evaporated mass inside and dispersion of the drops would occur. The picture that emerges now is that of non-negligible mass loss from the cluster, the cluster size initially decreasing and subsequently increasing, and correspondingly the drop number density initially increasing and subsequently decreasing. In all our calculations the cluster never recovered to its initial size.

Thus, our first task will be to check the qualitative features of the results by improving our model of heat and mass transfer across the boundary of the cluster.

Second, in the above formulation we treated the turbulence exchange processes by using Nusselt number correlations for turbulent flow around a sphere. This treatment has two implications. First, it assumes that the cluster is surrounded by several vortices and second, it implies that the turbulence length scale is much smaller than that of the cluster. This is to say that what was modeled was the situation that occurs for relatively large clusters of drops.

Small clusters of drops, such as those that are embedded in a single vortex, are not generally amenable to this particular formulation because the length scale of turbulence is of the same order of magnitude as that of the cluster. For this reason, we shall consider alternative ways of modeling these transport processes.

Based upon the above, during FY'88 we shall explore two processes: (1) transfer across the surface of the cluster for clusters small enough as to be embedded into one vortex and (2) motion of the vortex into which the cluster is embedded and the possible ejection of drops from the vortex due to the centrifugal force created by the rotation of the vortex.

References

1. Bellan, J. and Harstad, K., "The Details of the Convective Evaporation of Dense and Dilute Clusters of Drops," Int. J. Heat Mass Transfer, 30, 6, 1083-1093, 1987.
2. Bellan, J. and Harstad, K., "Turbulence Effects During the Evaporation of Drops in Clusters," submitted for publication.



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